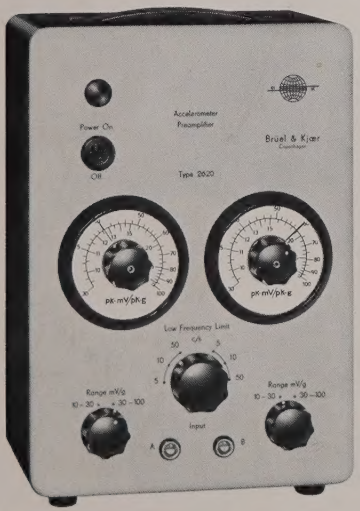
2620

INSTRUCTIONS AND APPLICATIONS

Accelerometer Preamplifier Type 2620



A two channel preamplifier for feeding accelerometer signals to vibration controlling and indicating equipment. The design obviates calibration of the measuring system.

- Accelerometers
- Acoustic Standing Wave Apparatus
- Artificial Ears
- Artificial Voices
- Audio Frequency Response Tracers
- Audio Frequency Spectrometers
- Audio Frequency Vacuum-Tube Voltmeters
- Automatic A. F. Response and Spectrum Recorders
- Automatic Vibration-Exciter Control Generators
- Band-Pass Filter Sets
- Beat Frequency Oscillators
- Complex Modulus Apparatus
- Condenser Microphones
- Deviation Bridges
- Distortion Measuring Bridges
- Frequency Analyzers
- Frequency Measuring Bridges
- Hearing Aid Test Apparatus
- Heterodyne Voltmeters
- Level Recorders
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- Vibration Pick-up Preamplifiers
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Accelerometer Preamplifier

Type 2620

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1. General

1.1. Purpose.
This instrument has two channels, one of them an interconnecting link between an accelerometer and the Automatic Vibration Exciter Control Type 1018/1038 or any suitable vibration meter, whilst the other channel can be used for monitoring the signal from a second accelerometer.
It performs three functions, which are set out in sections 1.2 to 1.4: note that the preamplifier itself does not provide velocity or displacement signals since the latest philosophy is to incorporate the necessary integrators in the main measuring instrument.

1.2. Impedance Transformation.
The preamplifier is placed as near as possible to the accelerometer in order to isolate the transducer from the influence of the long cables often necessary in practical arrangements. The accelerometer is then looking into an extremely high impedance which will not normally load it, and at the same time the low output impedance of the 2620 allows instruments and comparatively long cables to be connected to it without affecting the performance.

1.3. Gain Adjustment.
The Automatic Vibration Exciter Control is calibrated to give direct acceleration readings with an accelerometer of sensitivity 10 mV/g. Individual gain settings on each of the two channels of the preamplifier enable accelerometers of any sensitivity between 10 mV/g and 100 mV/g to deliver a signal to the measuring instruments which is accurately scaled to the standard sensitivity value. By means of a switch, either of the two accelerometers in use may be selected for the "main" measurement, whilst the signal from the other accelerometer is monitored at a separate output.

1.4. Shaping.
High Frequency. Although vibration tests are seldom carried out at frequencies above 10 kc/s and the mechanical resonance of accelerometers does not usually appear until above this frequency, it is nevertheless undesirable to allow the large gains associated with such a resonance. Harmonics of the drive frequency can sometimes excite this, with the result that equipment receiving the signal from the accelerometer may not behave correctly. To eliminate these unwanted high frequency signals, the 2620 incorporates low-pass filters cutting off above 10 kc/s.

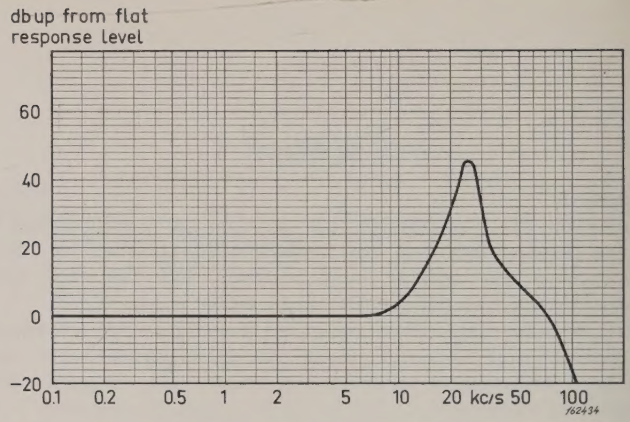

Fig. 1. The high frequency response of a typical accelerometer, showing the resonance peak.

Low Frequency. If the accelerometer is to sense low dynamic levels and its output is to be integrated either once or twice, thereby providing velocity or displacement readings respectively, the signal must be almost free of low frequency noise because integrators emphasise low frequencies.
To enable the indicating instruments to give a true displacement value, three alternative high-pass filters are built into the preamplifier, and the use of these is discussed in section 2.7.

2. Description

2.1. Block Diagram.

Fig. 2 shows how each of the two accelerometer channels has its own input cathode follower, but shares a common output stage. The high frequency cut-off and sensitivity adjustments are separate for each channel, but only the main output, which may be switched to either channel, benefits from the low frequency cut.

The functions of each block will now be considered in turn:

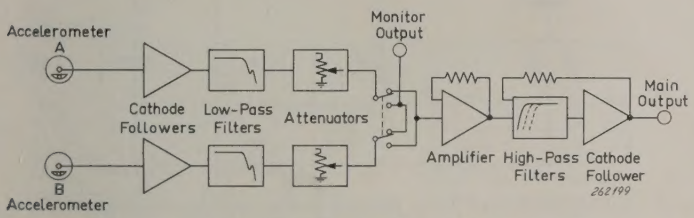

Fig. 2. Block diagram of the Accelerometer Preamplifier.

2.2. Input Circuits.

These are designed to present the highest possible impedance to the accelerometer and also to eliminate the effects of input cable capacitance. An input impedance of more than 600 MΩ in parallel with 10 pF has been achieved by careful choice of circuitry. The printed circuits used here are made in an unconventional manner, out of a special base material printed with contact gold. Silicone-based protective coatings prevent the flow of minutely small but troublesome cross-currents even under extremely humid conditions.

The impedance of a crystal accelerometer can be represented by a capacitance C_a pF, but normally it is not true to say that if a charge q appears on the faces of the piezoelectric crystal, there is a potential difference $\frac{q}{C_a}$ at the end of the accelerometer cable. The capacity of the cable, which is normally composed of a main cable plus a lead associated with the accelerometer, reduces the sensitivity. The effect of the accelerometer's associated lead is easily allowed for, but the different loads of various main cables and input circuits mean that it is usual practice to calibrate every set up independently in order to take account of an uncertain sensitivity.

One of the prime objects of the 2620 is to obviate this calibration and to this end the effective capacitance of the main cable and preamplifier input has been very much reduced.

This is achieved as shown in Fig. 12 by using twin-screened cable and connecting the inner screen to the input tube cathode so that its potential follows that of the central conductor. This means that there is almost no charge build up or decay in the grid circuits. The leads from the input sockets to the tube grids are similarly constructed and the 10 pF input capacitance mentioned earlier is an effective value, which rises to 25 pF if the inner screen is disconnected from the cathode.

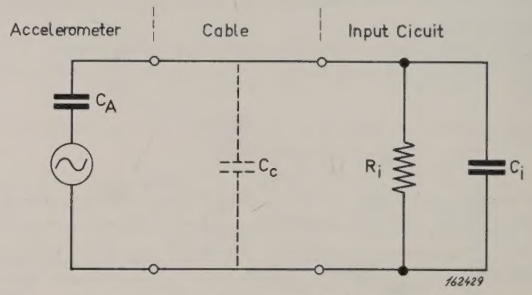

Fig. 3. Equivalent circuit of a piezoelectric accelerometer connected to one of the preamplifier's inputs.

As indicated in Fig. 3, the total capacitance in the input circuits, C_T, is made up from three capacities,

C_A = accelerometer capacitance, including associated lead,

C_c = overall effective capacitance of cable,

and C_i = input capacitance of preamplifier itself.

i.e. $C_T = C_A + C_c + C_i$.

C_A is usually large compared with C_c and C_i for the 2620 and provided an accuracy of $\pm$ 1 db is adequate, no sensitivity corrections are necessary.*) The frequency response of the input circuits should also be considered. At high frequencies the cathode follower performance falls off very slightly as explained in section 2.8, but the only significant attenuation occurs at very low frequencies where the accelerometer impedance becomes large compared with the input impedance. The loading effect of the preamplifier and cable will be

$$\frac{j\omega R_i C_A}{1 + j\omega R_i C_T'}$$

*) For very accurate work or when C_A is small, or C_c becomes significant (e.g. if the inner screen is disconnected or the cable is long), sensitivity deviations should be accounted for as explained in Appendix A.

which for most practical cases reduces to

$$\frac{j\omega R_1 C_A}{1 + j\omega R_1 C_A},$$

where ω is the angular frequency.

The corner frequency (— 3 db point) at which the accelerometer/preamplifier combination begins to exhibit a linear frequency characteristic is therefore given by

$$f_c = \frac{1}{2\pi R_1 C_A}.$$

Two common values for C_A are 400 pF and 1000 pF, so knowing this and the appropriate R_1, the low frequency response of the input circuits can be calculated: Figure 4. Either accelerometer feeding into a 600 MΩ input impedance gives a response which is perfectly flat down to 4 c/s, i.e. to below the usual frequencies for measurement.

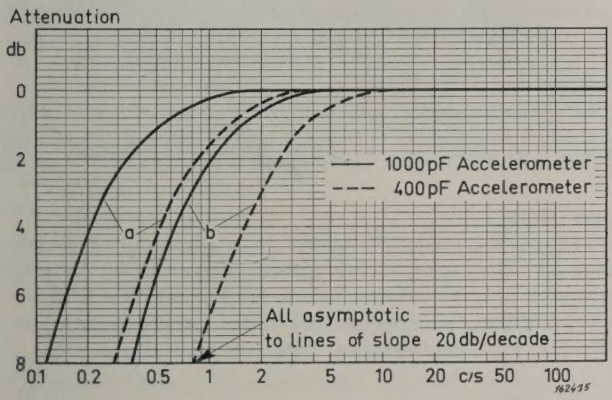

Fig. 4.

a) The low frequency response of the 2620 input circuits connected to accelerometers.

b) For comparison, the response for the same accelerometers when using common types of preamplifiers having an input impedance of 200 MΩ.

2.3. Low Pass Filters.

The characteristics for these filters, one in each a channel, are shown in Fig. 5. They are passive L-C circuits which in no way influence the low frequency response of the instrument, though in order to achieve the correct shaping they introduce a little attenuation which is, however, corrected for in the output amplifier. To eliminate pick-up of the power-line frequency and its harmonics, certain inductances are split.

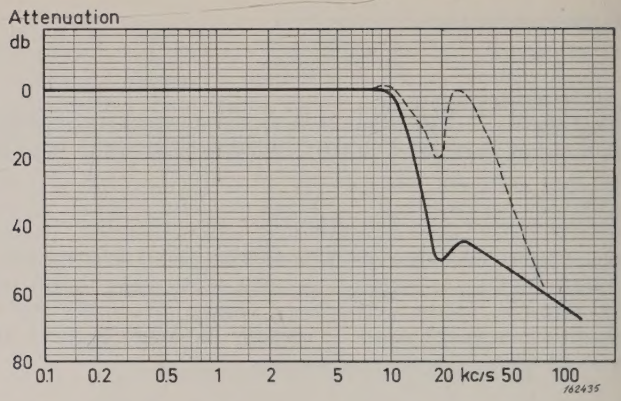

Fig. 5. Typical amplitude-frequency response for the low-pass filters. The broken line indicates the overall response of the preamplifier and an accelerometer with the characteristics shown in Fig. 1.

2.4. Attenuators.

Each of the two attenuators consists of a two-position coarse adjustment switch and also a fine control so that the overall gains of the two channels are separately and continuously variable over a range of 10 to 1, or 20 db.

2.5. Monitor Output.

Whichever signal is not selected for the main output appears here scaled to a constant 5 mV/g provided the transducer sensitivities lie within the prescribed range and the attenuators are correctly set.

The maximum output impedance is 10 kΩ, but this value decreases if the attenuator wiper is moved towards ground.

2.6. Output Amplifier.

This has a fairly high input impedance (400 kΩ) which will not load the attenuators. It is a single stage amplifier and the gain, tied down by negative feedback, is set to give the correct level (10 mV/g) at the main output.

2.7. High-Pass Filter.

As already pointed out in section 1.4, when reading small displacement signals at low frequency, the acceleration signal sensed by the transducer is minute, and so the noise voltages must be kept to an absolute minimum. As explained in the appendix it is extremely important to set the high-pass filters to as high a frequency setting as circumstances will allow. In this way the maximum amount of noise is rejected.

The high-pass filter is an active circuit in which there are three different pairs of condensers that can be switched in according to the cut-off frequency required.

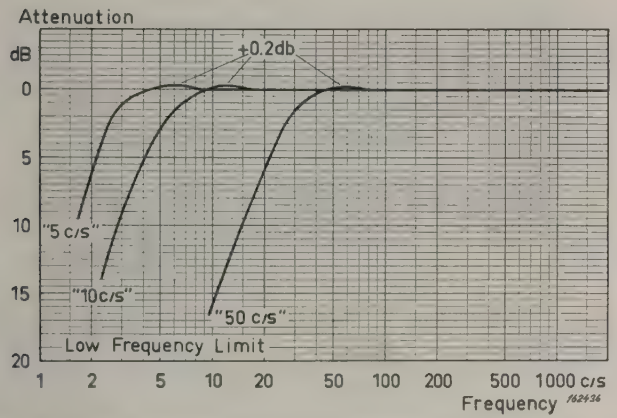

Fig. 6. Typical amplitude-frequency response for the high-pass filter.

2.8. Main Output.

Assuming that the accelerometer sensitivity lies between 10 mV/g and 100 mV/g, and that the controls are correctly adjusted, the signal scaling at this point is 10 mV/g.

The main output comes from a cathode follower with a low output impedance equivalent to less than 400 Ω in series with 8 μF.

The instruments fed by this preamplifier are likely to have an input impedance of about 80 kΩ so that at low frequencies the loading will be negligible. At high frequencies the capacitance of the output cable is the dominant factor, not only on account of a simple attenuation effect, but also because the load line of the output tube becomes distorted when the load is capacitive. This means that the total cable capacitance that can be used depends on frequency, voltage level and acceptable distortion. Fig. 7. indicates maximum values of capacitance for less than 3 % distortion, and it will be seen that for most practical applications a very long cable can be used: 100 pF per metre is quite a high value.

Referring to section 2.2 and to Fig. 12 it will be clear that the capacitance between the two screens of the input cables has a similar loading effect on the input cathode followers, (see Fig. 8), but this effect does not impose serious limitations in practice.

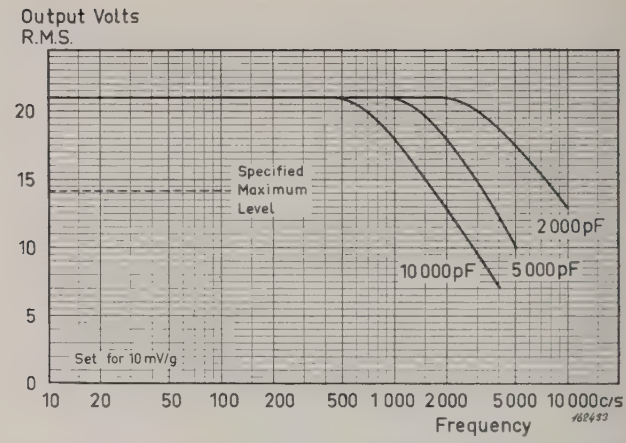

Fig. 7. Chart indicating the capacitive loading on the main output which results in 3 % overall distortion. The output is assumed to be connected to an Automatic Vibration Exciter Control (input impedance 80 kΩ). Distortion is not materially affected by the external capacitance between the preamplifier input feeder and ground, provided this capacity does not exceed 2000 pF. which covers all practical cases.

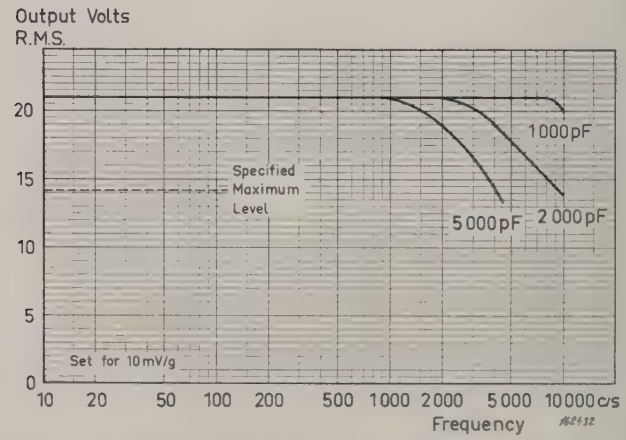

Fig. 8. Chart suggesting permissible capacity between the outer screen and the inner screen of each accelerometer cable. These are the capacitances such that the overall distortion through the preamplifier is 3 %, the only load being an Automatic Vibration Exciter Control.

2.9. Cross-Talk.
The cross-talk between the two channels is somewhat dependent on frequency, but is always more than 60 db down at frequencies above 10 c/s. From 5 c/s to 10 c/s it is about 50 db down.

2.10. Phase-Frequency Response.
The accelerometer preamplifier has been designed with a view to achieving certain attenuation characteristics and consequently exhibits phase advance (dependent on filter setting) at low frequencies and phase lag at high frequencies. It is not intended to be used for phase measurements.
There are no difficulties when making sweep sine tests in conjunction with the Automatic Vibration Exciter Control, but if the accelerometers are sensing complex signals (such as in shock tests), the various harmonics will experience different phase changes. An R.M.S. indicating instrument measuring the distorted signal will give the correct values, but an oscilloscope, "average" reading or peak reading voltmeter will give a false impression.

2.11. Power Supplies.
These have been very carefully designed to avoid injecting low frequency disturbances into the amplifier.
Most of the tubes are heated by stabilised DC in order to ensure a minimum of power line hum pick-up and low frequency drift.
The H.T. voltage is accurately regulated by a circuit containing two vacuum tubes and one gas-filled reference tube. A certain change in power line voltage results in an H.T. level alteration of only about one twentieth of this variation.

2.12. Noise.
Some practical hints for reducing noise are given in section 3.5.
Since it is too difficult to specify the noise voltage density at all frequencies, for all working conditions and a direct wideband measurement of noise is not particularly helpful, the Specification (Part 4.2) quotes the actual noise level appearing on the associated measuring instrument in the worst case.

Much of the troublesome noise is picked up in the accelerometer cables. Unfortunately any noise voltages generated between the central conductor and the inner screen (Fig. 12) are amplified several times by the first tube, and so under adverse conditions a higher effective cable capacity may have to be accepted and the inner screen disconnected. As explained in 2.2, individual calibration or correction rather than straightforward attenuator settings must be relied upon for correct scaling in this case.
The appendix shows the importance of reducing low frequency noise. Some of this, originating in the tubes, has been cut to a minimum in the 2620, but also a substantial part comes from the accelerometers themselves. Accelerometer noise is largely caused by air passing the sensitive element, and can be reduced by the use of wind shields. The higher the capacity of the accelerometer, the more easily can the noise currents leak away to ground.

3. Operation

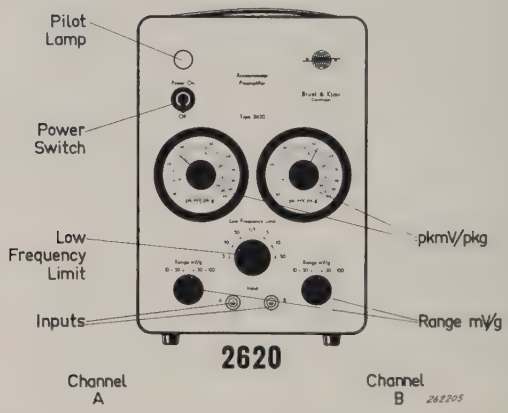

Fig. 9. Front view of the Accelerometer Preamplifier.

3.1. Controls and Sockets.

INPUT A and INPUT B are Lemo OM 2 × o.9 sockets*). Either one or two accelerometers can be fed to these points via twin-screened cable and a suitable plug. In each socket is a pin protected by a piece of Teflon: when the 2620 is live these must not be shorted to ground since they are at the potential of the input tube cathodes, about 60 v.

Channel A *pk.mV/pk.g* and RANGE mV/g control the attenuation in channel A so that accelerometers with various sensitivities give rise to a signal with a standard scaling in peak mV per peak g.

Channel B *pk.mV/pk.g* and RANGE mV.g control the attenuation in channel B quite independently of channel A.

LOW FREQUENCY LIMIT switch is used to rounte either channel A or channel B through to the main output and at the same time to select the desired low frequency limit for the main output signal

*) The corresponding plugs — B & K number JP 0201 — are coded F.OM2 × o.9 by their makers, Lemo AG, Route de Lausanne. Morges, Switzerland.

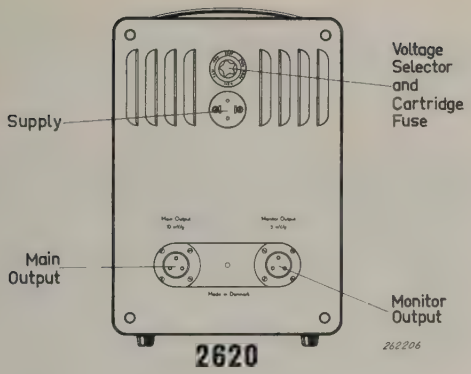

Fig. 10. View of the rear of the instrument.

MAIN OUTPUT is a cannon XH-3-14 socket delivering whichever signal has been selected (see above).

MONITOR OUTPUT is a Cannon XH-3-14 socket at which appears a signal from the channel not selected for the main output. The high-pass filter is not in this circuit so the low frequency limit is governed by the input circuit.

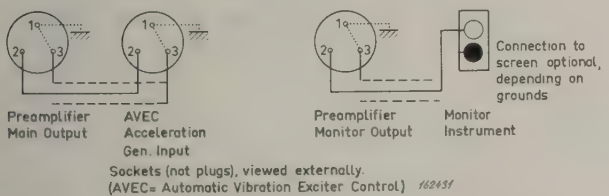

Fig. 11. Connections to the sockets. (Viewed externally.)

3.2. Power-line Voltage.

The preamplifier may be operated at any of the mains frequencies 50, 60, or 400 c/s, but the voltage selector must be correctly set to the supply voltage. If it is not, unscrew and withdraw the cartridge fuse and then, with the aid of a coin, turn the selector until the white bar is in the desired position. Replace the fuse.

3.3. Accelerometers.

Fig. 12 shows how the accelerometers should normally be connected via

twin-screened cable.*) The cables should preferably be not more than 5 metres long: Fig. 8 and section 2.8 explain the implications of having too much capacity between the inner and outer screens.

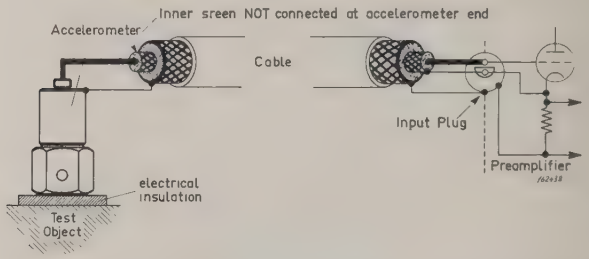

Fig. 12. The input cables should be connected in this manner. Each twin-screened cable is usually joined to the accelerometer's associated lead rather than running directly to the pick-up.

It is usually advisable to retain the single screened lead supplied with each accelerometer for the final connection to the pick-up itself. There are two reasons for this, a) the twin screened cable is rather stiff and heavy for some applications, and b) the accelerometer data normally refers to the output from this lead.

Connect the accelerometer(s) to Input A (and to Input B).

Select the two accelerometers to be used and determine for each its sensitivity, a figure that is usually quoted for every individual accelerometer by its manufacturer. Make sure this value refers to the condition *with* the associated lead which is normally in series with the twin-screened cable. If an accuracy of 1 dB is adequate, the effect of the twin-screened cable and input circuits on sensitivity is small enough to be neglected unless the accelerometer capacity is below 400 pF.**)

Switch the RANGE mV/g for each respective channel to the correct setting.

i.e. either 10—30 mV/g
or 30—100 mV/g.

Set the sensitivity value on the corresponding scale knob which may be locked in position by inserting an Allen key through the hole in the centre and turning clockwise.

If the accelerometer sensitivity lies outside the range 10 100 mV/g, the attenuator setting and vibration meter readings will have to be suitably

*) Note that the accelerometer should normally be isolated from ground.

**) When the given sensitivity values do not correspond with the arrangement as used (for instance if the accelerometer's associated lead is discarded), or if maximum accuracy is wanted, consult Appendix A.

scaled up or down. Bear in mind that the accelerometer signal level should be between 0.1 mV and 20 volts peak, and if the signal/noise ratio is to be satisfactory, should represent more than 0.1 g. Make sure that the accelerometer is shielded from draughts: wind noise can be a major problem.

3.4. Outputs.

The MONITOR OUTPUT may, if desired, be connected to an instrument such as a vacuum tube voltmeter or oscilloscope which should have an input impedance of at least 1 MΩ if any quantitative measurements are to be made. The MAIN OUTPUT is connected directly to the Acceleration Generator Input on the back of the 1018 Vibration Exciter Control, or to any other suitable vibration meter. See Fig. 11.

The length of cable which can be used depends upon:

The capacitance/unit length of the cable,
acceptable distortion,
voltage level,
frequency,
and terminating load.

Working up to 2000 c/s at maximum voltage levels with 50 metres of 100 pF/metre cable, the distortion will be less than 3 %. For further information, see Fig. 7.

Remember that the signal is still at a low level and hum and noise pick-up must be avoided.

Choose which channel is to be fed to the main output and turn the LOW FREQUENCY LIMIT switch to select this channel with the *highest* lower limiting frequency acceptable for the case in hand. The remaining channel is automatically switched to the monitor output.

3.5. Hum and Noise Reduction.

Although "field" tests away from other electrical equipment and multitudinous wiring are unlikely to raise problems in this respect, there are unfortunately hum and noise fields, sometimes powerful, in almost every indoor test room. Efforts must be made to cut down the effects of these, and if that is not successful, to reduce the fields at source. The following remarks are included as a guide to help those who are setting up a test system. Each problem must be solved by the user employing trial-and-error methods and building up experience.

Be careful to avoid earth loops, through which serious hum problems can arise. Make the screen of the main output cable the *only* connection between the chassis of the preamplifier and that of the main instrument. The P.A. is usually grounded so if the monitoring instrument has one input terminal grounded, the screen of the lead for the monitor signal should only be earthed at one end. Some pick-up will in these circumstances appear on the monitoring instrument, so if this is unacceptable the instrument must have

an input clear of ground, allowing a direct twin connection to the pre-amplifier. The mains transformer in a power amplifier may have considerable capacitance between its windings, so if such an amplifier is used it is best to ground it, making this the one and only earth point in the whole system.

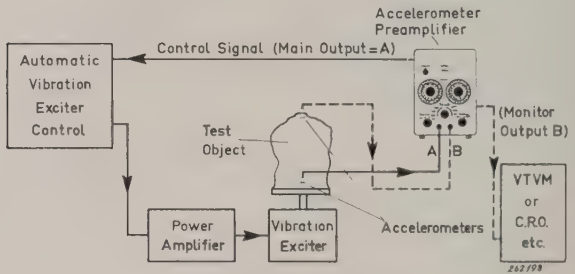

Fig. 13. A vibration test system.

The outer screens of the accelerometer leads should not reach an earth at both ends. Most **accelerometers** have their casing as one connection, so they **must not be in electrical contact with the test object** if it is a **grounded** metal structure.

The case of the 2620 is not directly connected to its chassis, so it is often possible to ground this case, thus improving screening.

See that there is a minimum of wind noise from the accelerometer. An efficient draught shield can be a great help even in an apparently still room. Change to an accelerometer of larger capacity and charge sensitivity if necessary and possible.

Provided a larger accelerometer cable effective capacitance is acceptable, (section 2.2), noise can be reduced by disconneting the inner screens of the accelerometer cables. See Fig. 12 and also section 2.12. This will involve setting corrections which are explained in Appendix A.

Extraneous noise can be particularly troublesome in test arrangements such as that shown in Fig. 13 because the R.M.S. value of the control signal becomes larger than it should be, possibly with the result that the shaker table stops vibrating. However, when the system is logically and tidily arranged, bearing in mind the above points, there should be no difficulties.

3.6. Warning.

Particularly when the preamplifier is in the feedback loop of a system controlling a vibration exciter, it is dangerous to unplug leads or switch knobs.

3.7. Warm-Up.

When the vibration test system is correctly set up, connect the preamplifier to the power line and switch on. Allow 5 minutes before taking any accurate measurements.

3.8. Application.

The preamplifier has been designed for use in conjunction with the Automatic Vibration Exciter Control Type 1018 or 1038 and reference should be made to the appropriate instruction manual. However, some of the advantages of the two-channel system will be briefly pointed out here.

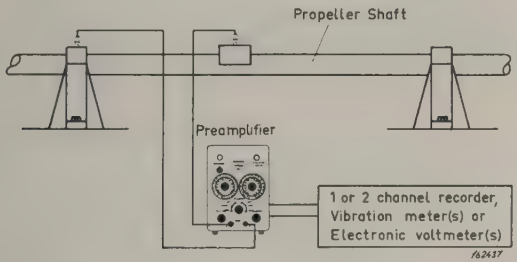

Fig. 14. A typical field test arrangement.

The main channel will often be used in the feedback path when the vibration exciter is being controlled in a closed loop system as in Figure 13. The "main" accelerometer is sensing the behaviour of the shaker table, but the second accelerometer can be used to monitor the vibrations of the test specimen itself. In this way much can be learnt, without the need for another preamplifier, about the mechanical transfer function of the specimen and about its various modes of vibration.

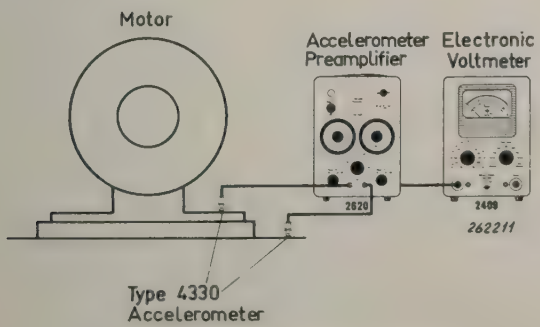

Fig. 15. Studying vibration insulation.

Again, in measurements under actual operating conditions, the two channel facility can be invaluable: vibration insulation tests are one example, and the study of propeller-shaft vibrations are another.

3.9. Summarized Procedure.

Sequence of Operations	*References* Sections	Figures
Mount accelerometer(s), electrically isolated from ground. Shield from wind.	3.5 2.12	
Connect accelerometer(s) to input(s) via twin screened cable(s) in series with the accelerometers associated leads.	3.1 2.2 Appx. A.	9 12 8
Set accelerometer mV/g with RANGE mV/g and *pk.mV/pk.g* for both inputs. Clamp dials.	3.1 3.3 2.4	 9
Select either Channel A or Channel B for MAIN OUTPUT, using LOW FREQUENCY LIMIT switch.	3.1 3.4	2
Set LOW FREQUENCY LIMIT to as high a frequency is acceptable.	3.1 3.4 2.7 Appx. B.	6
Connect MONITOR OUTPUT to V.T.V.M., oscilloscope etc. if desired. 5 mV/g.	3.1 3.4 2.5	10 11
Connect MAIN OUTPUT to ACCELERATION GENERATOR INPUT on back of Automatic Vibration Exciter Control.	3.1 3.4 2.8	10 11 7
Checking voltage selector panel, connect mains lead and switch Power "On". Allow 5 minutes to warm up.	3.2	10
Read **vibration levels directly** on main measuring instrument. Normally no calibration necessary.		
If noise difficulties arise, and when long or non-standard input cables are used, take special precautions.	2.2 2.12 3.5	

Appendix A.

Sensitivity Corrections.

Sensitivity corrections may sometimes have to be applied. Generally these need only be considered where

i) The accelerometer capacity is less than 400 pF;

or ii) The twin-screened cable is very long (more than 5 metres);

or iii) Noise problems necessitate disconnecting the inner screen of the cable;

or iv) Very accurate results are required.

As explained in 2.2, the effective sensitivity of an accelerometer is less than its open circuit sensitivity because the preamplifier is really only looking across part of a capacitive potential divider. Also, much will depend on whether or not the accelerometer's associated lead is used,—see Fig. 16 and note the definitions.

It is seen that

$$C_A = C_a + C_L, \qquad \ldots\ldots\ldots 1$$

$$\text{and } S_A = S_a \frac{C_a}{C_a + C_L} = S_a \frac{C_a}{C_A} \ldots\ldots\ldots 2$$

S_A is usually the figure given by the transducer manufacturers, likewise the specified frequency response etc. refers to the accelerometer and not to the

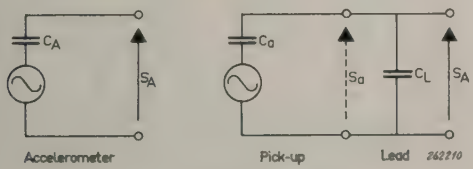

Fig. 16. Two equivalent circuits for the same accelerometer. An "accelerometer" is here defined as a vibration "pick-up" plus associated "lead".

S_A = accelerometer sensitivity,
C_A = accelerometer total capacity,
S_a = pick-up sensitivity (open circuit),
C_a = pick-up capacity,
and C_L = lead capacity.

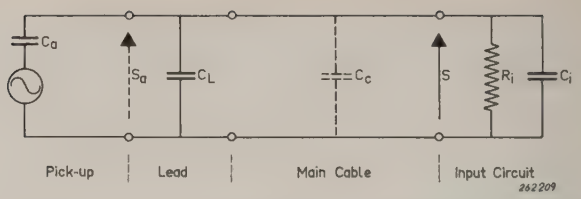

Fig. 17. Equivalent circuit of an accelerometer connected to the preamplifier's input terminals.

S = *effective sensitivity,*
C_e = *overall effective capacitance of main cable,*
C_i = *input capacitance of preamplifier itself,*
R_i = *input resistance.*
All capacities will be considered in pF.

pick-up. C_L is generally 100 pF as will be assumed here, although this value is not standardized.

Referring to Figs. 16 and 17, the effective sensitivity S is realated to S_A by the expression.

$$S = S_a \frac{C_A}{C_A + C_e + C_i}, \qquad \ldots\ldots\ldots 3A$$

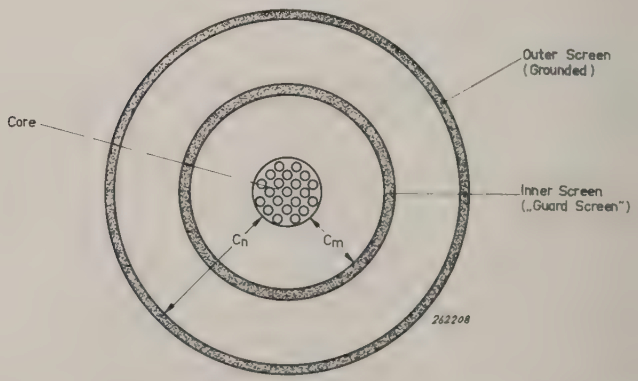

Fig. 18. Cross-section of a twin-screened cable, indicating the important capacitances.

C_m = *from core to inner screen,*
C_n = *from core to outer screen.*
Both are actual capacities governed by the construction of the cable.

which in terms of open-circuit parameters (sometimes given) becomes, by equation 2:

$$S = S_a \frac{C_a}{C_a + C_L + C_c + C_i}. \qquad \ldots\ldots\ldots 3B$$

C_i can be taken as 10 pF, and $C_L = 100$ pF.

To find C_c, consider first a cross-section of a twin-screened cable (Fig. 18). If the inner screen is not connected $C_c = C_n$ and if the two screens are both earthed C_c would be larger, equal to C_m. C_m and C_n are easily found by multiplying the correct capacity per unit length (from the cable manufacturer's tables) by the length, or alternatively from measurements.

When both screens are used, the input circuits are working on the "guard-ring" principle and C_c is not the same as the capacity which would be deduced by considering the construction of the cable alone. Fig. 19 shows

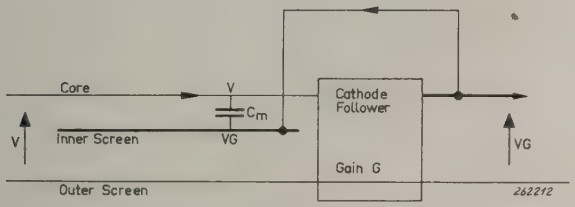

Fig. 19. Schematic diagram showing how the cathode follower output is fed back to the inner screen of the input cable.

that the output of the cathode follower is fed back to the guard screen, so the potential difference across C_m is $V - VG$. C_m has an impedance $\frac{1}{j\omega C_m}$ at angular frequency ω, so the current leakage away from the core is

$$i = \frac{V - VG}{\frac{1}{j\omega C_m}} = j\omega C_m V (1 - G), \qquad \ldots\ldots\ldots 4$$

if all paths other than those in the cable itself are neglected. This is justified because the preamplifier input leakage has already been taken into account. The cable impedance is therefore

$$Z = \frac{V}{i} = \frac{V}{j\omega C_m V (1 - G)} = \frac{1}{j\omega C_m (1 - G)}. \qquad \ldots\ldots\ldots 5$$

Throughout most of the frequency range there is no phase shift through the cathode follower so that G is real, its value being 0.95. The cable impedance is then a pure capacitance of value $(1 - 0.95)\ C_m$.

Experiments show that there is in addition an end-effect which, to a sufficient degree of accuracy, is equivalent of a constant 12 pF.

$$\text{i.e. } C_e = (0.05\, C_m + 12)\ \text{pF}. \qquad \ldots\ldots\ldots\ 6$$

This formula is modified somewhat at the extreme ends of the frequency range because the cathode follower introduces some phase shift which means that G becomes complex. However, for practical purposes, equation 6 can always be taken as valid and it agrees well with measurements.

In terms of practical data, the various formulae can be re-stated thus:

1. Inner screen connected, complete accelerometer used.

$$S = S_A \frac{C_A}{C_A + 0.05\, C_m + 22}\ \text{mV/g}$$

from equations 3A and 6.

2. Inner screen connected, pick-up alone.

$$S = S_A \frac{C_A}{C_A + 0.05\, C_m - 78}\ \text{mV/g}$$

from equations 1, 2, 3B and 6. Note that the effective sensitivity may well be greater than S_A in this case. If S_A is say 9 mV/g, S could be brought within the scale range of the preamplifier.

3. Inner screen disconnected, complete accelerometer used.

$$S = S_A \frac{C_A}{C_A + C_n + 10}\ \text{mV/g}$$

putting $C_e = C_n$ in equation 3A.

4. Inner screen disconnected, pick-up alone.

$$S = S_A \frac{C_A}{C_A + C_n - 90}\ \text{mV/g}$$

from equation 3B.

Examples:

Accelerometer data (calibrated with 100 pF lead):

$C_A = 400$ pF

$S_A = 57.6$ mV/g.

5 metres of twin-screened cable, capacities:

Core/inner screen 85 pF/metre,

Core/outer screen 65 pF/metre,

Inner screen/outer screen 257 pF/metre.

Hence $C_m = 5 \times 85 = 425$ pF.

$C_n = 5 \times 65 = 325$ pF.

Case 1:

$$S = \frac{57.6 \times 400}{400 + 21.2 + 22} = 52\ \text{mV/g}$$

Here the compensation is 9.8 % (0.8 dB), which would not be worth correcting for in many applications.

Case 2:

$$S = \frac{57.6 \times 400}{400 + 21.2 - 78} = 67.1 \text{ mV/g}$$

Set 67 mV/g

Case 3:

$$S = \frac{57.6 \times 400}{400 + 325 + 10} = 31.3 \text{ mV/g}$$

Set 31.3 mV/g

Case 4:

$$S = \frac{57.6 \times 400}{400 + 325 - 90} = 36.2 \text{ mV/g}$$

Set 36.2 mV/g

Note concerning distortion:
In cases 1 and 2 there is $5 \times 257 = 1285$ pF loading the cathode follower. Fig. 8 shows that distortion will be about 3 % at 10 kc/s with maximum input levels.

Appendix B.

Noise, and its Reduction by the Use of Filters.

It was stated in sections 2.7 and 3.4 that the Low Frequency Limit switch should be set to as high a frequency as possible. In order to explain the importance of correctly setting this control and to point out some of the difficulties which are inherent in any low frequency vibration measuring system, the following calculation is included here.

It will be initially assumed that, after eliminating line frequency hum, most of the noise present is thermal noise generated in the circuit components. The noise voltage ΔV generated within a certain small band of frequencies of width $\Delta\omega$ rad. sec.$^{-1}$ is given by

$$\Delta V^2 = K\Delta\omega,$$

where K is a constant for a given circuit at a given temperature. Furthermore, if the noise is taken to be "white", that is to say that the noise voltage density is the same at all frequencies, then K is independent of frequency. ω is angular frequency, which in this case varies between a lower limit (L) and a higher limit (H), so that if B is the bandwidth over which the noise is passed, $B = \int_{\omega = L}^{\omega = H} d\omega$, and the total noise voltage is derived by integration to be

$$V \propto \sqrt{B}.$$

The higher limiting frequency (H) may be taken as fixed at 10 kc/s, but 3 values of lower limiting frequency (L) are available. Changing L from 5 c/s to 50 c/s reduces the bandwidth by about 0.5 % but does not appreciably improve the noise level on an acceleration signal. However, the effect of integration must now be considered.

Using the suffices A and D to indicate acceleration- and displacement-noise voltages respectively, it will be clear that if the former is considered as a sinusoidal signal, then after two integrations:

$$\Delta V_D = \frac{-\Delta V_A}{\omega^2}.$$

However, ΔV_A is the original thermal noise voltage and is therefore given by

$$\Delta V_A^2 = K\Delta\omega;$$

$$\text{i.e. } \Delta V_D^2 = \frac{K\Delta\omega}{\omega^4}$$

Summing all the elements contributing to the displacement signal noise voltage, the total noise over the whole bandwidth from $\omega = L$ to $\omega = H$ is found to be

$$V_D^2 = \frac{-K}{3}\left[\omega^{-3}\right]_L^H.$$

Since the higher limit of ω is comparatively large,

$$\boxed{V_D \propto \omega_L^{-3/2}}.$$

It can now be appreciated that the cut off frequency of the high-pass filter should be set as high as possible; in other words not too far below the lowest frequency required for measurement. Altering L from 5 c/s to 50 c/s improves the displacement signal noise level more than 30 times.

This discussion was based on the assumption that the noise is truly "white". In fact thermal noise as considered so far forms only a part of the total unwanted signal since tube and accelerometer noise should also be included. The low frequency components are predominant in these cases which means that the low frequency cut-off becomes even more important and the "improvement" figure just quoted would be far more than 30.

4. Specification

4.1. Inputs.

Two identical channels.

Impedance:	Greater than 600 MΩ, in parallel with 10 pF.
Transducers:	Feed from crystal accelerometers, capacity preferably more than 160 pF.
Transducer Sensitivity:	Preferably between 10 mV/g and 100 mV/g.
Input Voltage Level:	Fore reliable measurement, between o.1 mV and 20 volts peak.
Gains:	1 to 1/10. Set separately for each channel by controls calibrated directly in accelerometer peak mV/peak g. Accelerometer signals transferred to standard scaling with accuracy $\pm$ 2 %. Stability better than $\pm$ 1 % when power line voltage varies $\pm$ 10 %.

4.2. Main Output.

High Frequency Limit:	(o.5 db point): 10ooo c/s.
Low Frequency Limit:	(o.25 db point): 5, 10, or 50 c/s as required.
Frequency Response:	Flat within $\pm$ o.2 db from low frequency limit to 5ooo c/s, o.5 db $\pm$ o.5 db down at 10ooo c/s.
Scaling:	10 mV/g.
Output Impedance:	Less than 400 Ω in series with 8 μF.
Hum and Noise Level:	(Worst case) With 300 pF on input, 5 c/s lower limiting frequency, and the preamplifier followed by two integrators with 5 c/s corner frequencies, the displacement signal noise level is better than 30 μV, i.e. equivalent to about o.003″ or 77 μmetre.

Cross Talk	from monitor channel: Above 10 c/s, more than 60 db down. From 5 c/s to 10 c/s, 50 db down.
Distortion:	Better than 1.5 % for input levels below 20 volts peak. (Preamplifier only.)

4.3. Monitor Output.

H.F. Cut-off:	10ooo c/s.
L.F. Cut-off:	Usually determined by input circuit lower limit.
Frequency Response:	Similar to that for main output but linear range extending down to L.F. cut-off. (See above).
Scaling:	5 mV/g.
Output Impedance:	10ooo Ω maximum.
Cross Talk	from main channel: Above 10 c/s, more than 60 db down. From 5 c/s to 10 c/s, 50 db down.
Distortion:	As for main channel.

4.4. General.

Tubes:	2 × 12AT7 (ECC81), 1 × 6AU6 (EF94), 1 × 12B4, 1 × 85A2.
Semiconductor Devices:	1 × ASZ16, 1 × 1312, 4 × 2E4, 2 × OA211.
Mains Supply:	100—115—127—150—220 and 240 volts (± 10 %), 50, 60, or 400 c/s.
Dimensions:	Height 10″ (26 cms) Width 7″ (18 cms) Depth 5″ (13 cms) Weight 12½ lbs. (5 kg) approx.
Accessories	supplied with the 2620: 1 power cable, 2 input plugs, 2 output plugs, 2 Allen keys for clamping dials, spare panel lamp and fuses.

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